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Automatic imitation? Imitative compatibility affects responses at high perceptual load

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Abstract

Imitation involves matching the visual representation of another's action onto the observer's own motor program for that action. However, there has been some debate regarding the extent to which imitation is "automatic" – i.e., occurs without attention. Participants performed a perceptual load task in which images of finger movements were presented as distractors. Responses to target letter stimuli were performed via finger movements which could be imitatively compatible (requiring the same finger movement), or incompatible, with the distractor movements: in this common stimulus-response compatibility manipulation, the stimulus set comprises images of the response movements, producing an imitative compatibility effect. Attention to the distractor movements was manipulated by altering perceptual load through increasing the number of non-target letter stimuli. If imitation requires attention, then at high perceptual load, imitative compatibility should not affect response times. In contrast, imitative compatibility influenced response times at high perceptual load, demonstrating that distractor movements were processed. However, the compatibility effect was reversed, suggesting that longer response times at high perceptual load tap into an inhibitory stage of distractor movement processing. A follow-up experiment manipulating temporal delay between targets and distractor movements supported this explanation. Further experiments confirmed that non-movement distractor stimuli in the same configuration produced standard perceptual load effects, and that results were not solely due to effector compatibility. These data suggest that imitation can occur without attention.

Keywords: automatic imitation; attention; social cognition; stimulus-response compatibility; perceptual load

Humans imitate the movements of their interaction partners, copying body language, gestures, and posture. This mimicry of others' actions is thought to be important for social interaction (Chartrand & Bargh, 1999; Chartrand & Lakin, 2013). It is also thought to be unintentional, that is, non-deliberate: we imitate without intending to and may be unaware that we are doing so.

The psychological function unique to imitation is the ability to match the visual representation of another's action onto the observer's own motor program for that action (Heyes, 2001). In order to isolate this function in the laboratory, stimulus-response compatibility experiments have been developed in which both stimuli and responses comprise configural body movements. On each trial of such experiments, a formally task-*irrelevant* movement stimulus is presented, alongside a task-*relevant* imperative cue to which a response movement must be made (see Figure 1A). The identity of the task-irrelevant movement stimulus is manipulated such that it is either compatible (activating the same response) or incompatible (activating a different response) with the required response movement. Compatible trials reliably elicit faster response times to the cue than do incompatible trials, demonstrating an imitative compatibility effect: a stimulus-response compatibility effect in which compatibility is defined in terms of the configural body movements that comprise the stimulus and response sets (Heyes, 2011; Stürmer, Aschersleben, & Prinz, 2000). The presence of such an effect suggests that the visual representation of the irrelevant movement stimulus is matched onto the observer's motor representation of the same movement, thus facilitating responses on compatible trials and interfering with responses on incompatible trials. Importantly, such an effect is independent of spatial compatibility, remaining present when spatial compatibility is controlled (Bertenthal, Longo, & Kosobud, 2006; Catmur & Heyes, 2011).

The present study investigated the extent to which such imitative compatibility effects occur without attention. This is of relevance for several reasons. There has been some debate (Heyes, 2011; Liepelt & Brass, 2010; Liepelt, von Cramon, & Brass, 2008) regarding whether imitative compatibility effects are automatic, that is non-controlled, processes; and one test of whether a process is automatic is whether it occurs without attention (Shiffrin & Schneider, 1977). One reason to question whether imitative compatibility effects are the result of an automatic process is the finding that such effects, unlike spatial compatibility effects, seem to increase as response time increases (Brass, Bekkering, & Prinz, 2001; Pfister, Dignath, Hommel, & Kunde, 2013). This could indicate that imitative compatibility effects are the result of a controlled, rather than an automatic, process. Alternatively, it could be due to the relative perceptual complexity of the movement stimuli involved in imitative compatibility tasks: it may take longer to discriminate two body movement stimuli from each other than it takes to discriminate two spatial locations (Catmur & Heyes, 2011).

Another reason to test whether imitation can occur without attention is that the social psychological literature on naturalistic mimicry suggests that such phenomena do indeed take place without attention (Chartrand & Bargh, 1999). Evidence that imitation can occur without attention would add to evidence that lab-based imitation experiments using stimulus-response compatibility paradigms are measuring the same psychological function as more naturalistic studies. Finally, the question of whether attention is required to process a stimulus addresses the debate regarding the presence of specialised or privileged processing mechanisms for social versus non-social stimuli (e.g. Gauthier et al., 2014; McKone, Kanwisher, & Duchaine, 2007; Mitchell, 2008; Scholz, Triantafyllou, Whitfield-Gabrieli, Brown, & Saxe, 2009). It has previously been demonstrated that familiar faces, but not other objects, can be identified without attention (Lavie, Ro, & Russell, 2003), suggesting that social stimuli may be processed by a different or privileged mechanism which requires less attention than other types of stimuli. However, it is not clear whether such privileged processing applies to other social stimuli: Burton and colleagues (2009) found that eye gaze did not influence responses when presented outside the focus of attention, suggesting that attention is required to process others' eye gaze. Therefore it still remains unclear whether non-face social stimuli such as body movements can be processed without attention.

Bach, Peatfield and Tipper (2007) demonstrated that attending to a particular body part in a stimulus image facilitated the performance of movements using that body part, compared to movements using a different body part (a body-part or *effector* compatibility effect). When attention was directed to a neutral location on the image, no effector compatibility effect occurred, suggesting that effector compatibility effects require attention. However, this study did not measure *imitative* compatibility: that is, this effect was not specific to the particular configural body movement that was observed; in fact it occurred regardless of whether the observed body part was performing a movement or not.

Chong, Cunnington, Williams and Mattingley (2009) also aimed to address the question of whether imitative compatibility effects occur without attention. On every trial of a go-nogo task, participants were told to prepare one of two movements, and then either to perform or to withhold the prepared movement depending upon which of two movement stimuli were presented (one of which was compatible and one incompatible with the prepared response). Which movement stimulus corresponded to the ‘go’ and which to the ‘nogo’ cue alternated in blocks across the course of the experiment. This experiment revealed an apparent imitative compatibility effect, such that response times to perform the prepared movement were faster when that movement was compatible with the ‘go’ stimulus, than when it was incompatible. Subsequent experiments demonstrated that this compatibility effect did not occur when attention was diverted from the movement-relevant features of the stimulus, suggesting that the effect required selective attention to the movement stimulus in order to occur. However, it is not clear that this is indeed an effect of imitative compatibility: instead, it could be an effect of movement preparation on perception (e.g. Wohlschläger, 2000; Press, Gherri, Heyes, & Eimer, 2010), whereby the preparation of a movement facilitates the perception of a compatible stimulus, speeding response times on compatible trials. This interpretation is rendered more likely because of the nature of the task, which requires a fine perceptual discrimination between the two movement stimuli: a requirement that is not present in other stimulus-response compatibility studies of imitative compatibility in which the identity of the movement stimulus is task-irrelevant. Thus the finding that this particular effect requires attention in order to occur does not address the question of whether imitative compatibility effects require attention.

In order to investigate whether imitative compatibility effects can occur without attention, the present study used a modified version of Lavie (1995)'s perceptual load task. Lavie demonstrated that attention to task-irrelevant distractor stimuli is reduced by increasing the perceptual load of a central task. Participants were asked to respond to the identity of a target letter (an X or an N) while ignoring distractor letters presented above or below the target area. Distractors could be compatible (same letter, activating the same response) or incompatible (the other letter, activating the alternative response) with the target letter. Perceptual load of the central task was modulated by presenting the target letter amongst a varying number of non-target letters which were neutral with respect to the response set (i.e. they did not correspond to either possible response). At low levels of perceptual load (no or one non-target letter), the identity of the distractor letter influenced response times, producing a compatibility effect. When perceptual load was increased (three or five non-target letters), distractor stimuli no longer influenced response time to the central task; this is thought to occur because the high perceptual load of the central task occupies all attentional resources, thus leaving no attention to process the distractor stimuli. Perceptual load manipulations have been shown to modulate not only response times to task-irrelevant distractors but also neural responses to task-irrelevant stimuli (Rees, Frith, & Lavie, 1997; Yi, Woodman, Widders, Marois, & Chun, 2004) and cortical excitability of non-task-relevant brain areas (Muggleton, Lamb, Walsh, & Lavie, 2008): a pattern of results consistent with the hypothesis that increasing the perceptual load of a task reduces attention to, and processing of, task-irrelevant stimuli.

Therefore, the present study manipulated attention to task-irrelevant finger movements by altering perceptual load. On every trial, one of two target letters was presented either alone or with one, three or five non-target letters, producing four levels of perceptual load. Responses to the target letters comprised finger tapping movements of either the index or middle fingers. An irrelevant stimulus hand was also presented and performed a task-irrelevant finger tapping movement on every trial. The distractor movement could therefore be compatible (same finger movement) or incompatible (movement of the alternative finger) with the response required to the target letter. Response times to perform a tapping movement in response to the target letter were measured on compatible and incompatible trials at each level of perceptual load.

If imitation requires attention, then no effect of imitative compatibility should be found at high levels of perceptual load. Conversely, if an effect of imitative compatibility is found at high perceptual load, it suggests that irrelevant finger movements are processed, and activate the corresponding motor program in the observer, even when attention to those movements is reduced by the attentional demands of the task.

Experiment 1

Methods

Participants

28 undergraduate students (four male, three left-handed) aged 18-44 (mean ± standard deviation 19.8 ± 4.8) participated in partial fulfilment of a course requirement and were randomly allocated to one of two groups in order to counterbalance target letter – response finger mappings. For all experiments, participants gave their informed consent to participate and the experimental procedures were approved by the University of Surrey Research Ethics Committee.

Stimuli

The irrelevant hand stimulus comprised an image of a left hand positioned in the centre of the screen such that the wrist was on the left of the screen and the fingers pointed towards the right side of the screen (Figure 1A). This positioning ensured there was no spatial compatibility between the stimulus and response hands (participants always responded using their right hand). The index and middle fingers of the hand started in a lifted position. The target letter (X or N) and accompanying non-target letters (randomly selected from H, K, M, W, and Z) were presented in a horizontal line, the vertical position of which was midway between the index and middle fingers of the hand. The horizontal location of the target letter amongst the accompanying letters was varied randomly across trials. The irrelevant finger movement comprised a single downward movement of the index or middle finger (Figure 1B and 1C). Apparent motion was used to ensure the irrelevant movement was presented simultaneously with the target and non-target letters; thus the irrelevant finger movement stimuli comprised images of the end-points of either index or middle finger tapping actions.

Figure 1 about here

Procedure

On each trial, a fixation cross was presented for 500ms, followed by the irrelevant hand stimulus and fixation cross which was presented for a variable duration between 960ms and 1980ms. Subsequently, the target letter, the irrelevant finger movement and (where applicable) the additional non-target letters were presented for 500ms. Finally a blank screen was presented until a response was detected or up to a maximum of 1500ms.

The experiment was programmed, stimuli were presented, and responses collected using E-Prime 2.0 (Psychology Software Tools, PA) running on a PC. Stimuli were presented on a 17" screen and responses were made via the computer keyboard.

Participants were instructed to look at the location of the fixation cross throughout the experiment, to respond as quickly and as accurately as possible to the target letter by performing a key press with the relevant finger, and to ignore distractor finger movements. Participants in the first counterbalancing group were instructed to respond to the presence of a letter X by performing an index finger key press (1 on the numerical keypad); and to respond to the presence of a letter N by performing a middle finger key press (pressing 2). Participants in the second counterbalancing group received the opposite letter-response mapping.

The variables of target letter (X, N), target location (6 possible locations), perceptual load (1, 2, 4 or 6 items), and compatibility between response finger and irrelevant distractor finger (compatible, incompatible) were combined in a full factorial design to give 96 different trial types. Each trial type was presented once per block of trials, in a randomised order. Three blocks were administered for a total of 288 trials, resulting in 36 trials for each level of compatibility at each level of perceptual load. Before the first block, 16 randomly selected practice trials were administered, with visual feedback after each trial ("Correct" / "Incorrect"). Participants had to achieve an 80% level of accuracy on these practice trials to commence the first block of the experiment. If this level was not achieved, participants repeated the 16 trials until this criterion was achieved. In the experimental blocks, no feedback was provided. Participants could take a short break between blocks, each of which took around seven minutes to complete.

Response times and accuracy were recorded. Trials on which an error was made, or on which the response time was more than 2.5 standard deviations from the participant's mean response time for that condition (i.e. for each cell of the load x compatibility design), were removed from the response time analysis. For the remaining trials, mean response time for each level of compatibility at each level of perceptual load was calculated for each participant. Where response time effects were significant, errors were also analysed to ensure the RT effects could not be due to a speed-accuracy tradeoff.

Results

Five participants who made more than 20% errors were removed, leaving a sample of 23 participants.

Mean ± standard error of the mean (SEM) response times for each level of imitative compatibility at each level of perceptual load are displayed in Figure 2. Response time data were analysed using repeated-measures analysis of variance (ANOVA) with within-subjects factors of imitative compatibility (compatible, incompatible) and load (1, 2, 4, and 6 items). A main effect of load was found, $F_{3,66} = 161.52$, $p < .001$, $\eta^2_p = .880$, indicating that response times increased with load. The main effect of imitative compatibility did not reach significance, but an interaction between load and imitative compatibility was observed, $F_{3,66} = 4.22$, $p = .009$, $\eta^2_p = .161$. Figure 2 suggests that the effect of imitative compatibility reversed as load increased, such that at higher loads, response times were faster for incompatible than for compatible trials. Planned comparisons of the simple effects of imitative compatibility at each level of load revealed a significant effect of imitative compatibility at a load of 6 items, $F_{1,22} = 5.48$, $p = .029$, $\eta^2_p = .199$. This indicates that at the highest level of perceptual load, response times were significantly faster for incompatible than for compatible distractor movements.

Figure 2 about here

The same analysis performed on the error data (Figure 2) revealed only a main effect of load, $F_{3,66} = 18.53$, $p < .001$, $\eta^2_p = .46$, indicating that errors increased with load.

Discussion

Experiment 1 demonstrated that imitative compatibility can affect response times at high perceptual load, indicating that imitation may not require attention. However, the compatibility effect was reversed, suggesting that although processing of the irrelevant finger movement did occur, it resulted in inhibition – rather than facilitation – of the associated response. This could be related to the longer response times found at high levels of perceptual load, which may tap into an inhibitory processing stage of the irrelevant movement, producing a negative compatibility effect (Eimer & Schlaghecken, 2003).

It is unclear whether the results of Experiment 1 are due solely to the configural movement properties of the irrelevant stimulus (the specific movement of the finger with respect to the rest of the hand, i.e. 'flexion away from the plane of the other raised finger towards the palm') or instead are also due to *effector* compatibility (the finger identity, i.e. index or middle). In other words, it may be that the movement of the irrelevant finger activated a matching movement representation in the observer, but it may also be the case that any stimulus which primes one finger identity rather than the other will activate the response associated with that finger; and it is unclear whether imitative compatibility, effector compatibility, or both are contributing to the effects of perceptual load on compatibility seen in Experiment 1.

Finally, it may be that the complex perceptual nature of the irrelevant hand stimulus creates a high perceptual load even when single targets are used, as in the lowest perceptual load condition of Experiment 1. If that were the case, it may be that it is not possible to obtain a standard pattern of perceptual load effects (i.e. compatibility effects at low but not at high perceptual loads) with this stimulus configuration. Although this could not easily explain the reversed compatibility effect seen at the highest level of perceptual load in Experiment 1, it is still important to ascertain whether it is indeed possible to obtain standard perceptual load effects for non-movement distractors using these perceptually complex stimuli.

Therefore, three follow-up experiments were run, addressing each of the above concerns. Experiment 2 tested whether it is possible to obtain standard perceptual load effects in this stimulus configuration. Experiment 3 tested whether the results of Experiments 1 and 2 could be explained by effector compatibility. Finally, Experiment 4 investigated whether the reversed compatibility effect found in the first experiment could be explained by response-time-dependent inhibition of the response associated with the irrelevant finger movement.

Experiment 2

Experiment 2 tested whether a standard effect of perceptual load (i.e. an influence of task-irrelevant distractor stimuli on response times at low, but not at high, levels of perceptual load) can be obtained when these particular hand stimuli are presented, because it could be argued that these stimuli may have increased perceptual complexity and thus impaired the ability of Experiment 1 to show a standard perceptual load effect. The presence of a standard perceptual load effect was tested using distractor letter stimuli in order to make the manipulation as similar as possible to that of Lavie (1995), while also including the hand stimuli in order to assess any effect of increased perceptual complexity on the perceptual load effect. A standard perceptual load effect would manifest itself as an influence of the distractor letter stimuli on response times at low, but not at high, levels of perceptual load. An absence of a perceptual load effect in Experiment 2 would indicate that the results of Experiment 1 might not be interpretable in the way they were intended, because it would suggest that these particular hand stimuli impair the ability to detect a standard perceptual load effect, and therefore experiments using these stimuli are not informative with regards to how perceptual load impacts on processing of body movement stimuli.

Experiment 2 manipulated target-distractor compatibility at each of four levels of perceptual load, using the same manipulation as Lavie (1995): on compatible trials, the distractor stimulus comprised the same letter as the target, while on incompatible trials it was the alternative letter. The target letter and additional non-target letters were presented between the index and middle fingers of an irrelevant hand stimulus, as in Experiment 1; but contrary to Experiment 1, the fingers did not perform any movements. The distractor letters were presented on the index and middle fingertips of the irrelevant hand stimulus.

Methods

Participants

23 undergraduate students (three male, four left-handed) aged 18-21 (mean ± standard deviation 19.0 ± 0.8) participated in partial fulfilment of a course requirement and were randomly allocated to one of two counterbalancing groups.

Stimuli

Stimuli (Figure 1D and 1E) were identical to Experiment 1 with the exception that no irrelevant movements were presented; instead, a distractor letter (X or N) was presented on either the index or middle fingertip of the irrelevant hand. The distractor was either compatible (same letter) or incompatible (other letter) with the target letter. In order to keep the number of trials constant across experiments, effector compatibility was not manipulated: thus the distractor letters were always presented on the fingertip corresponding to the response that should be elicited by that letter (e.g. if the distractor letter was an X, then for participants in the X->index target-response mapping group, it was presented on the index finger).

Procedure

The procedure was identical to that of Experiment 1 with the exception that no irrelevant movements were presented; instead, on each trial a distractor letter was presented simultaneously with the target letter and any non-target letters. Participants were instructed to ignore distractor letters.

Results

Four participants who made more than 20% errors were removed, leaving a sample of 19 participants.

Mean ± SEM response times for each level of letter compatibility at each level of perceptual load are displayed in Figure 3. Response time data were analysed using repeated-measures ANOVA with within-subjects factors of letter compatibility (compatible, incompatible) and load (1, 2, 4, and 6 items). A main effect of load was found, $F_{3,54} = 99.90$, $p < .001$, $\eta^2_p = .847$, indicating that response times increased with load. There was no main effect of letter compatibility, and the interaction between load and letter compatibility did not reach significance ($p = .150$). Figure 3 does, however, suggest that an effect of letter compatibility is present at the lowest level of load. Planned comparisons of the simple effects of letter compatibility at each level of load revealed a significant effect of letter compatibility at a load of 1 item, $F_{1,18} = 8.19$, $p = .010$, $\eta^2_p = .313$. This indicates that at the lowest level of perceptual load, response times were significantly faster for compatible than for incompatible distractor letters.

Figure 3 about here

The same analysis performed on the error data (Figure 3) revealed a main effect of load, $F_{3,54} = 17.84$, $p < .001$, $\eta^2_p = .498$, indicating that errors increased with load. Planned comparisons of the simple effects of letter compatibility at each level of load revealed a significant effect of letter compatibility at a load of 1 item, $F_{1,18} = 9.01$, $p = .008$, $\eta^2_p = .334$. This indicates that at the lowest level of perceptual load, significantly fewer errors were made for compatible than for incompatible distractor letters.

Discussion

Experiment 2 found a significant effect of letter compatibility at the lowest level of perceptual load and no effects at any other level of perceptual load. This pattern of responses is similar to the perceptual load effects found in experiments by Lavie and colleagues, although the presence of the irrelevant hand stimulus may have increased perceptual load such that sufficient attentional resources to process distractor stimuli were only present at the lowest level of load, making it harder to detect an interaction (in essence, perceptual load reached a ceiling at a load of two items when combined with the irrelevant hand stimulus). In any case, the presence of a distractor letter compatibility effect at the lowest load and not at higher levels indicates that standard perceptual load effects can be obtained using this stimulus configuration. This result confirms that Experiment 1's results can be interpreted in the intended way.

However, in this experiment the compatibility between target and distractor letters was confounded with effector compatibility: that is, the distractor letter was always presented on the tip of the finger which corresponded to the response which would be activated by that distractor letter. This was by design: fully to cross the factors of target-distractor compatibility and effector compatibility would have required twice as many trials, which was undesirable; the alternative, which would be to hold effector compatibility constant (e.g. always compatible: placing the distractor letter on the fingertip corresponding to the response which should be made to the target) could have reduced the possibility of finding a perceptual load effect if participants implemented strategic responding based on the location of the distractor letter.

Thus the results of Experiment 2 suggest that standard perceptual load effects can be obtained using this stimulus configuration, but it is still possible that the letter compatibility effect found at the lowest level of perceptual load was due to effector compatibility, rather than being an effect of distractor-target *letter* compatibility. Experiment 3 tested this possibility, alongside the possibility that effector compatibility could explain the results of Experiment 1.

Experiment 3

Experiment 3 tested whether the results of either Experiments 1 or 2 could be due to the effect of perceptual load on effector compatibility, i.e. due to increasing the salience of a particular finger identity (index or middle), rather than an effect on imitative compatibility (Experiment 1) or on distractor-target letter compatibility (Experiment 2).

Experiment 3 manipulated effector compatibility at each of four levels of perceptual load. On compatible trials, a distractor stimulus (a letter O) was presented on the irrelevant hand, on the fingertip of the effector corresponding to the response which should be made to the target, while on incompatible trials it was presented on the fingertip of the effector which did not correspond to the target response. The target letter and additional non-target letters were presented between the index and middle fingers of the irrelevant hand stimulus, as in Experiments 1 and 2, but the fingers did not perform any movements.

Methods

Participants

30 undergraduate students (five male, three left-handed) aged 18-33 (mean ± standard deviation 19.4 ± 3.0) participated in partial fulfilment of a course requirement and were randomly allocated to one of two counterbalancing groups.

Stimuli

Stimuli (Figure 1F and 1G) were identical to Experiment 2 with the exception that effector compatibility was manipulated by presenting a distractor letter O on either the index or middle fingertip of the irrelevant movement hand. On compatible trials this was the fingertip of the effector corresponding to the response which should be made to the target, while on incompatible trials it was the other fingertip.

Procedure

The procedure was identical to that of Experiment 2 with the exception that the distractor letter was an O presented on the effector which was compatible or incompatible with the required response.

Results

One participant who made more than 20% errors was removed, leaving a sample of 29 participants.

Mean ± SEM response times for each level of compatibility at each level of perceptual load are displayed in Figure 4. Response time data were analysed using repeated-measures ANOVA with within-subjects factors of effector compatibility (compatible, incompatible) and load (1, 2, 4, and 6 items). A main effect of load was found, $F_{3,84} = 141.05$, $p < .001$, $\eta^2_p = .834$, indicating that response times increased with load. The main effect of effector compatibility and the interaction between load and effector compatibility did not reach significance, and planned comparisons revealed no effects of effector compatibility at any level of load.

Figure 4 about here

The same analysis performed on the error data (Figure 4) revealed a main effect of load, $F_{3,84} = 26.62$, $p < .001$, $\eta^2_p = .487$, indicating that errors increased with load.

Discussion

Experiment 3 found no evidence for effector compatibility effects at any level of perceptual load. This suggests that the results of Experiments 1 and 2 are not due solely to effector compatibility.

However, in order to ascertain that effector compatibility is having no effect at any level of perceptual load, it would be necessary to test whether the results of either of the first two experiments are significantly different from those of Experiment 3. In follow-up analyses comparing each of Experiments 1 and 2 to Experiment 3, the interaction terms including the factor of experiment did not reach significance. Therefore, it is possible that effector compatibility is contributing to the findings of Experiment 1, but that alone, it is not sufficiently strong to produce the same pattern of results. It may therefore be possible that both finger movement, and finger identity, can be processed under conditions of reduced attention.

Experiment 4

Having established that it is possible to obtain standard perceptual load effects with the current stimuli and procedure, and that neither these effects nor those of Experiment 1 are due solely to effector compatibility, Experiment 4 investigated the source of the reversed imitative compatibility effect found at high perceptual load in Experiment 1.

Certain models of motor control suggest that responses associated with task-irrelevant stimuli are activated, and then later inhibited, producing negative compatibility effects (e.g. Eimer & Schlaghecken, 2003). In Experiment 1, this would mean that the irrelevant finger movement activated the matching response in the observer, and that this response was initially facilitated and subsequently inhibited. Since response times to perform the task in Experiment 1 were relatively long (550-850ms), especially for high levels of perceptual load, it is plausible that the motor representation activated by the irrelevant finger movement was in the inhibition phase of processing at the time when response selection occurred, and that this inhibition produced a reduced or reversed imitative compatibility effect.

If this is the case, then the presence – and direction – of imitative compatibility should depend on the stage of processing reached by the irrelevant movement stimulus at the time of response selection. Experiment 4 therefore manipulated the processing stage that the irrelevant movement stimulus might be hypothesised to have reached at the time of response selection, by delaying the onset time of the irrelevant finger movement with respect to the onset time of the target letter. This manipulation was performed between participants, to keep the total number of trials constant across experiments. All other details of the experiment were identical to that of Experiment 1.

Methods

Participants

79 undergraduate students (16 male, 11 left-handed) aged 18-30 (mean ± standard deviation 19.4 ± 2.2) participated in partial fulfilment of a course requirement. Participants were randomly allocated to one of four delay conditions, and within each delay condition to one of two counterbalancing groups.

Stimuli

Stimuli (Figure 1B and 1C) were identical to Experiment 1.

Procedure

On each trial, a fixation cross was presented for 500ms, followed by the resting hand stimulus with superimposed fixation cross which was presented for a variable duration between 960ms and 1980ms. Subsequently, the target letter and (where applicable) the additional non-target letters were presented for one of four delays: 0ms (no delay; identical to Experiment 1); 150ms; 300ms; and 450ms. Thus the target letter underwent a variable amount of processing, depending on this delay, before the irrelevant finger movement was then presented. The target and non-target letters remained on the screen for an additional 500ms during presentation of the irrelevant finger movement (Figure 1H). Finally a blank screen was presented until a response was detected or up to a maximum of 1500ms. Delay was manipulated between participants. All other details were identical to Experiment 1.

Results

Three participants with outlying response times and five who made more than 20% errors were removed, leaving a sample of 71 participants distributed as follows across the four delay conditions: 0ms delay – 17; 150ms delay – 19; 300ms delay – 19; 450ms delay – 16.

Mean ± SEM response times and errors for each level of imitative compatibility at each level of perceptual load are displayed for each delay condition in Table 1. Response time data were analysed using mixed ANOVA with between-subjects factor of delay condition (0ms, 150ms, 300ms, and 450ms delay between target letter onset and distractor finger movement) and within-subjects factors of imitative compatibility (compatible, incompatible) and load (1, 2, 4, and 6 items). A main effect of load was found, $F_{3,201} = 435.62$, $p < .001$, $\eta^2_p = .867$, indicating that response times increased with load. The main effects of imitative compatibility and of delay condition, and the interaction between these effects, did not reach significance. A significant interaction was observed between load and imitative compatibility, $F_{3,201} = 3.56$, $p = .015$, $\eta^2_p = .05$; however, this interaction was modulated by delay condition, resulting in a significant three-way interaction between delay condition, load, and imitative compatibility, $F_{9,201} = 1.99$, $p = .042$, $\eta^2_p = .082$. This three-way interaction followed a linear trend, as would be predicted if it depended on the delay condition: $F_{3,67} = 2.84$, $p = .044$, $\eta^2_p = .113$. This result suggests that the effect of perceptual load on the magnitude and direction of the compatibility effect depends on the delay between the cue and the irrelevant movement distractor. The interaction between imitative compatibility and delay condition also followed a linear trend, $F_{1,67} = 4.28$, $p = .043$, $\eta^2_p = .064$, suggesting that the size of the compatibility effect increased across delay conditions, from a more negative compatibility effect when delays between target letters and irrelevant movement were shorter and thus processing of the irrelevant movement would have been in an inhibitory phase at the time of response selection, to a more positive effect at longer delays, when processing of the irrelevant movement would have been in a facilitatory phase.

Table 1 about here

The same ANOVA performed on the error data revealed a main effect of load, $F_{3,201} = 65.86$, $p < .001$, $\eta^2_p = .496$, indicating that errors increased with load.

In order to visualise how delaying the processing of the irrelevant movement impacted on the magnitude of the imitative compatibility effect, the magnitude of the compatibility effect (response time on incompatible – response time on compatible trials) for each level of perceptual load in each delay condition was plotted (Figure 5) as a function of the elapsed time between the onset of the irrelevant movement and response time (as a proxy for response selection time). It can be observed that the sign of the compatibility effect is positive for short elapsed times, when processing of the irrelevant movement is hypothesised to be in a facilitatory phase; whereas for longer elapsed times it shows a negative sign, consistent with the hypothesis that processing of irrelevant stimuli enters an inhibitory phase at longer response times. The data from Experiment 1 are also plotted for comparison purposes.

Figure 5 about here

Discussion

Experiment 4 demonstrated that the size and direction of the imitative compatibility effect can be modulated by manipulating the stage of processing which the irrelevant movement stimulus has reached at the time of response selection. When the irrelevant movement stimulus is presented a relatively short time before the response, the imitative compatibility effect is positive, indicating that processing of the irrelevant movement is in a facilitatory phase. At longer elapsed times between onset of the irrelevant movement stimulus and response selection, processing of the irrelevant movement enters an inhibitory phase, resulting in negative compatibility effects. These results indicate that irrelevant finger movements can influence response times regardless of perceptual load, but that the direction of that influence will depend on the stage of processing reached by the irrelevant movement at the time of response selection.

This experiment also demonstrates that imitative compatibility can be affected by inhibitory processes during perceptual processing and response selection, in the same way as priming effects found in other, non-social domains. It therefore supports the case for imitative compatibility being a particular type of stimulus-response compatibility effect (Heyes, 2001; 2011), rather than an entirely separate process (Bertenthal & Scheutz, 2013).

General Discussion

The present study sought to establish whether imitation can occur without attention. Experiments 1 and 4 demonstrated that imitative compatibility affects response times at high perceptual load: that is, under conditions where attention to the irrelevant movement stimuli should be reduced, these stimuli still influenced response times. Experiment 2 demonstrated that it is in principle possible to find a standard pattern of perceptual load effects using the stimuli of Experiments 1 and 4, and that therefore the findings of Experiments 1 and 4 cannot be due to the perceptual demands of the task. Finally, Experiment 3 demonstrated that the results of the other experiments were not due solely to effector compatibility but (at least to some extent) are due to the configural movement properties of the irrelevant finger movements (Experiments 1 and 4) and to the identity of the irrelevant letter stimuli (Experiment 2).

It should be noted that at the lowest load condition in Experiment 1, the effect of imitative compatibility – although in the expected direction – did not reach significance. This is likely to be a Type II error due to sampling noise: inspection of the data revealed that the failure to find a significant effect of compatibility in this condition was driven by the presence of a multivariate outlier whose imitative compatibility effect was almost four standard deviations below the group mean. It is also relevant to point out that the identical condition in Experiment 4 (load of 1 at 0ms delay) did show a significant effect of imitative compatibility. Thus it is likely that with a larger sample, the imitative compatibility effect in the lowest load condition of Experiment 1 would also have reached significance.

The results of Experiment 4 suggest that the reversed compatibility effect found at high levels of perceptual load may be due to the inhibition of imitative responses at later stages of processing. Another way to test this account is to carry out a response time distribution analysis, in order to assess whether it is indeed the case that fast response times produce positive compatibility effects and slow response times produce negative compatibility effects. To this end, the data from

Experiment 1, with the exception of the multivariate outlier mentioned above, were combined with those participants from Experiment 4 who performed the identical task (the group who performed the task with 0ms delay), yielding a sample size of 39 participants. For each participant, response times for each level of imitative compatibility were divided into five quintiles from fastest to slowest response time, and mean response time was calculated. These data were then subjected to ANOVA with factors of imitative compatibility (compatible, incompatible) and quintile (fastest to slowest). A main effect of quintile, $F_{4,152} = 479.31$, $p < .001$, $\eta^2_p = .927$, and an interaction between quintile and compatibility, $F_{4,152} = 8.28$, $p < .001$, $\eta^2_p = .179$, were found. Planned comparisons of the simple effects of imitative compatibility at each quintile revealed a significant positive effect of imitative compatibility at the fastest response times, $F_{1,38} = 4.46$, $p = .041$, $\eta^2_p = .105$, and a significant negative effect at the slowest response times, $F_{1,38} = 5.85$, $p = .020$, $\eta^2_p = .133$, supporting the suggestion that the longer response times for the high perceptual load condition led to negative imitative compatibility effects in Experiments 1 and 4.

Crucially, regardless of its direction, the presence of an imitative compatibility effect at high perceptual load indicates that the task-irrelevant movement is being processed and is influencing response times. These data therefore suggest that the psychological function unique to imitation, that is the mapping of an observed movement onto the observer's motor program for that movement, can occur under conditions of limited attention. These results therefore support the view that imitative compatibility effects are a form of automatic imitation (Heyes, 2011).

These data add to evidence that lab-based experiments are measuring the same function as that which takes place in more naturalistic studies in which imitation occurs without attention (Chartrand & Bargh, 1999). In addition, these data are consistent with the existence of specialised or privileged processing for social stimuli: they indicate that social stimuli such as faces (Lavie et al., 2003) and finger movements either require less attention to be processed, or capture limited attentional resources more effectively, than non-social stimuli. In support of this conclusion, Ro and colleagues

(2007) demonstrated that both faces and static images of body parts produced increased attentional capture in a visual search task.

The present data do not address the question of to what extent any such privileged processing may be the result of evolutionary pressures (e.g. due to the importance of processing social stimuli), as opposed to the result of experience gained during development (i.e. extensive experience of processing social stimuli). However, it has been demonstrated that expertise with a stimulus category can provide immunity from perceptual load effects: in contrast to musically naive participants, participants with high levels of musical expertise processed images of musical instruments even under conditions of high perceptual load (Ro, Friggel, & Lavie, 2009). In the case of imitation, therefore, it also appears plausible that any privileged processing may result from experience, because the function – unique to imitation – of mapping observed onto performed movements has been demonstrated to be highly experience-dependent (for reviews, see Catmur, 2013; Cook, Bird, Catmur, Press, & Heyes, 2014). Under this account, the sight of a finger movement is so strongly associated with the performance of that finger movement that it activates the motor program for that movement even under conditions of limited attention. Future studies could however investigate this question directly, by testing whether newly-learned associations between observed and performed movements (for example, the association between the sight of an index finger movement and the performance of a middle finger movement) are still expressed under conditions of limited attention.

If imitation can occur without attention, this suggests that imitative compatibility may indeed be a result of processes that are non-controlled or automatic (in the sense of occurring with limited attention). This seemingly contrasts with the findings of Liepelt and colleagues (2010; 2008) who suggested that observers' top-down beliefs about stimulus animacy and movement intentionality influence the extent to which they will imitate others' actions. If imitation (i.e. the activation of a motor representation by a visual representation of the same action) can occur under conditions of limited attention, then it would not be necessary for the imitator to hold a belief about the animacy or intentionality of the observed action in order for imitation to occur. However, the finding that imitation can occur without (or with limited) attention does not preclude the possibility that increasing attention to a visual representation of an action may enhance imitation of that action. Indeed, increasing attention to, and thus processing of, an action is likely to enhance the ability to imitate that action. What the present data do show, however, is that we do not need fully to attend to others' actions in order for those actions to activate our own motor programs.

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Table 1

Delay condition	Imitative compatibility	Perceptual load (number of items)												Overall compatibility effect
		1 item			2 items			4 items			6 items			
		RT	errors	CE	RT	errors	CE	RT	errors	CE	RT	errors	CE	
0 ms (n=17)	Compatible	561±16	1.3±0.3	27±12	635±18	2.2±0.5	-10±11	750±27	2.8±0.5	-20±14	873±37	3.9±0.6	-45±21	-11.6±10.1
	Incompatible	588±22	2.9±0.4		625±17	2.6±0.4		731±21	2.9±0.7		829±31	5.2±0.8		
150 ms (n=19)	Compatible	523±13	2.3±0.7	3±6	573±14	2.3±0.4	6±9	682±22	2.2±0.4	-4±15	760±23	5.7±1.0	-3±14	0.4±8.1
	Incompatible	526±11	1.5±0.4		579±10	2.3±0.5		678±13	3.3±0.7		756±23	4.3±0.6		
300 ms (n=19)	Compatible	535±15	1.8±0.4	6±6	606±18	2.8±0.4	5±10	702±19	4.3±0.6	11±9	798±30	6.8±1.0	12±15	8.7±7.3
	Incompatible	541±14	2.1±0.5		612±16	2.3±0.5		713±21	3.4±0.5		810±30	6.3±0.8		
450 ms (n=16)	Compatible	535±19	1.4±0.3	19±8	589±18	2.8±0.5	15±9	678±19	3.5±0.6	25±14	795±40	6.1±1.0	-8±21	12.8±8.6
	Incompatible	554±21	2.0±0.4		605±19	3.1±0.5		703±29	3.8±0.8		786±39	5.6±0.7		

Table 1. Mean ± SEM response time (RT; in ms), number of errors, and compatibility effect (CE; incompatible RT – compatible RT, in ms) for each level of imitative compatibility at each level of perceptual load, along with the overall compatibility effect across all levels of perceptual load, in the four delay conditions of Experiment 4.

Figures and Figure Captions

Figure 1

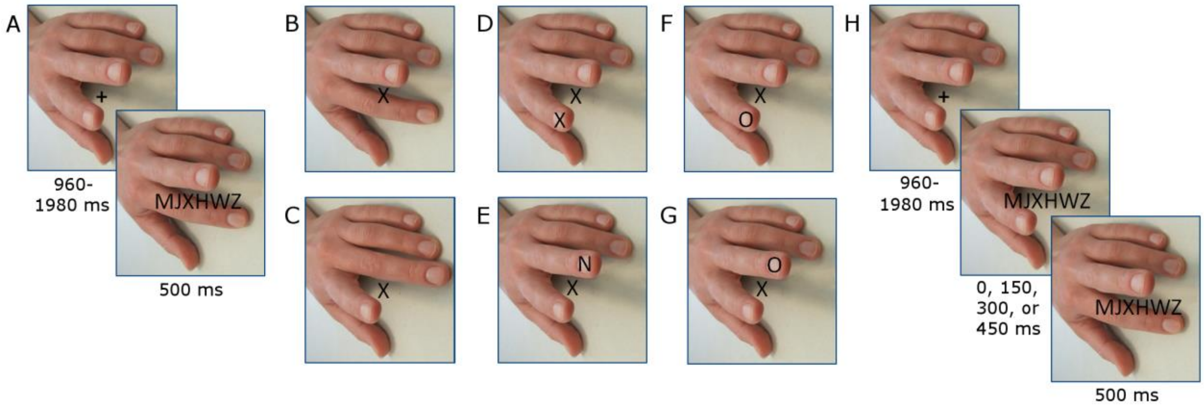

Figure 1. Stimuli and timings. A. Timing of stimulus presentation for Experiments 1-3. A high perceptual load condition (6 items) is shown. B-G. Examples of stimuli in the lowest perceptual load condition for each experiment (B, C: Experiments 1 and 4; D, E: Experiment 2; F, G: Experiment 3). For participants who received the target letter-response mapping of X=> index finger response, the upper line denotes compatible trials and the lower line incompatible trials. H. Timing of stimulus presentation for Experiment 4, in which the onset of the irrelevant finger movement was delayed between participants.

Figure 2

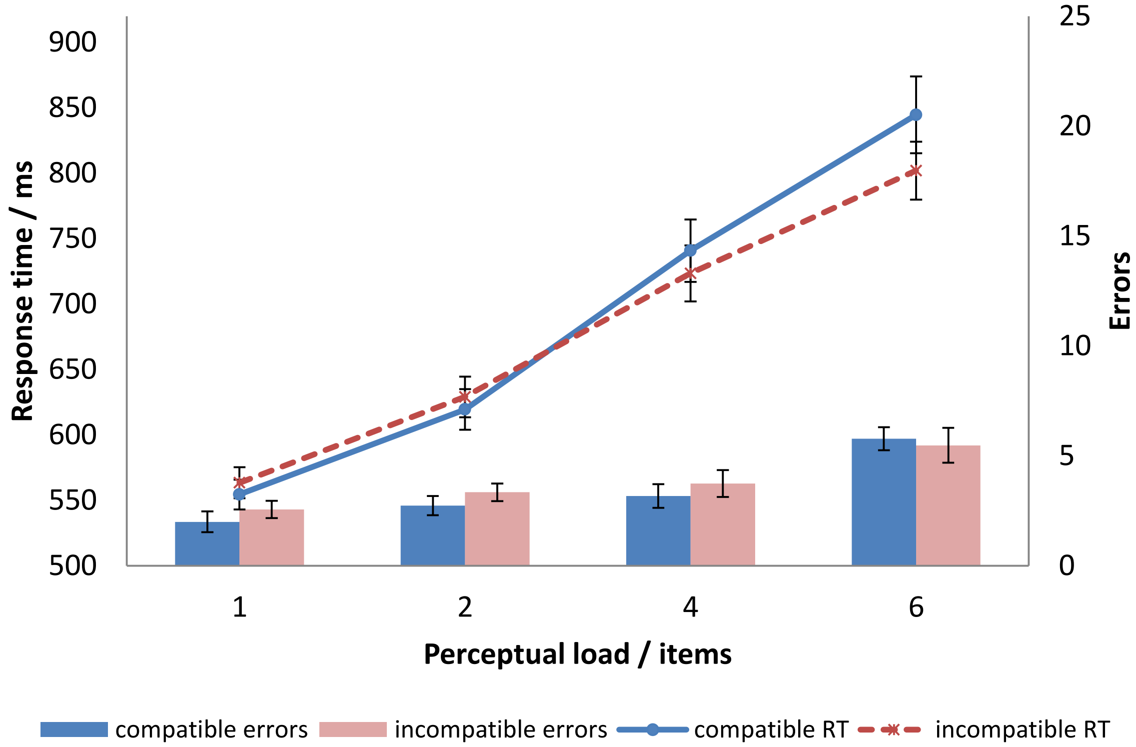

Figure 2. Response time and errors in Experiment 1 for compatible and incompatible distractor finger movements at each level of perceptual load. Error bars indicate standard error of the mean.

Figure 3

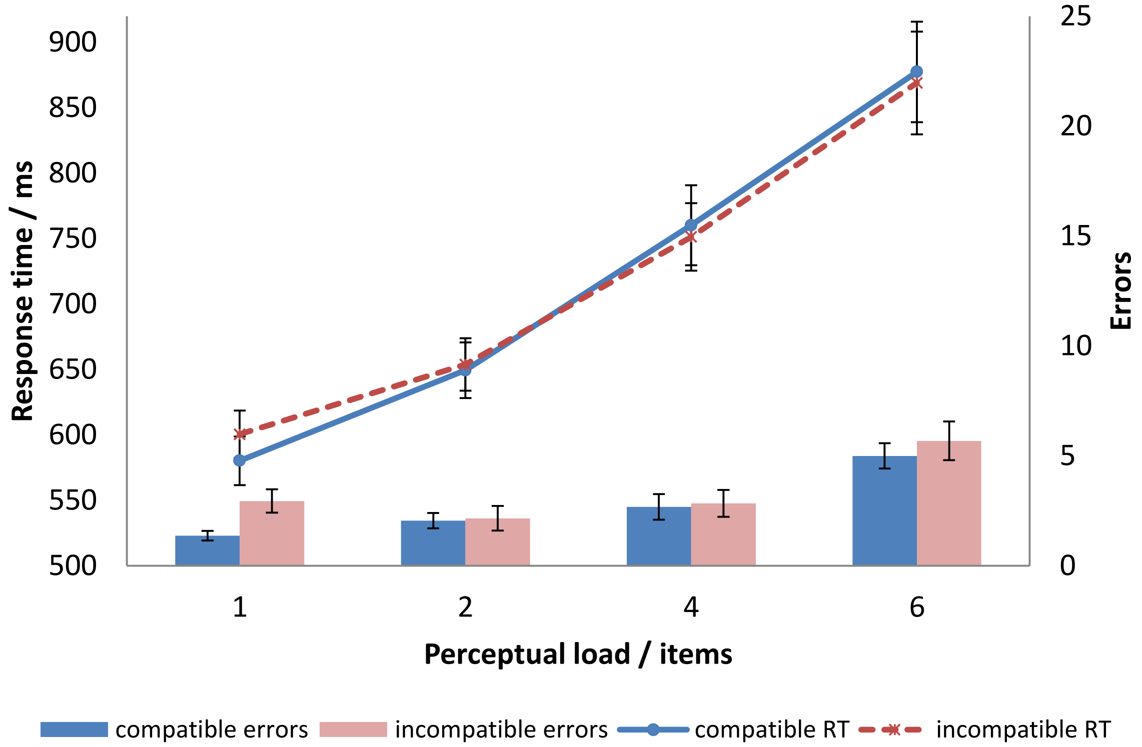

Figure 3. Response time and errors in Experiment 2 for compatible and incompatible distractor letters at each level of perceptual load. Error bars indicate standard error of the mean.

Figure 4

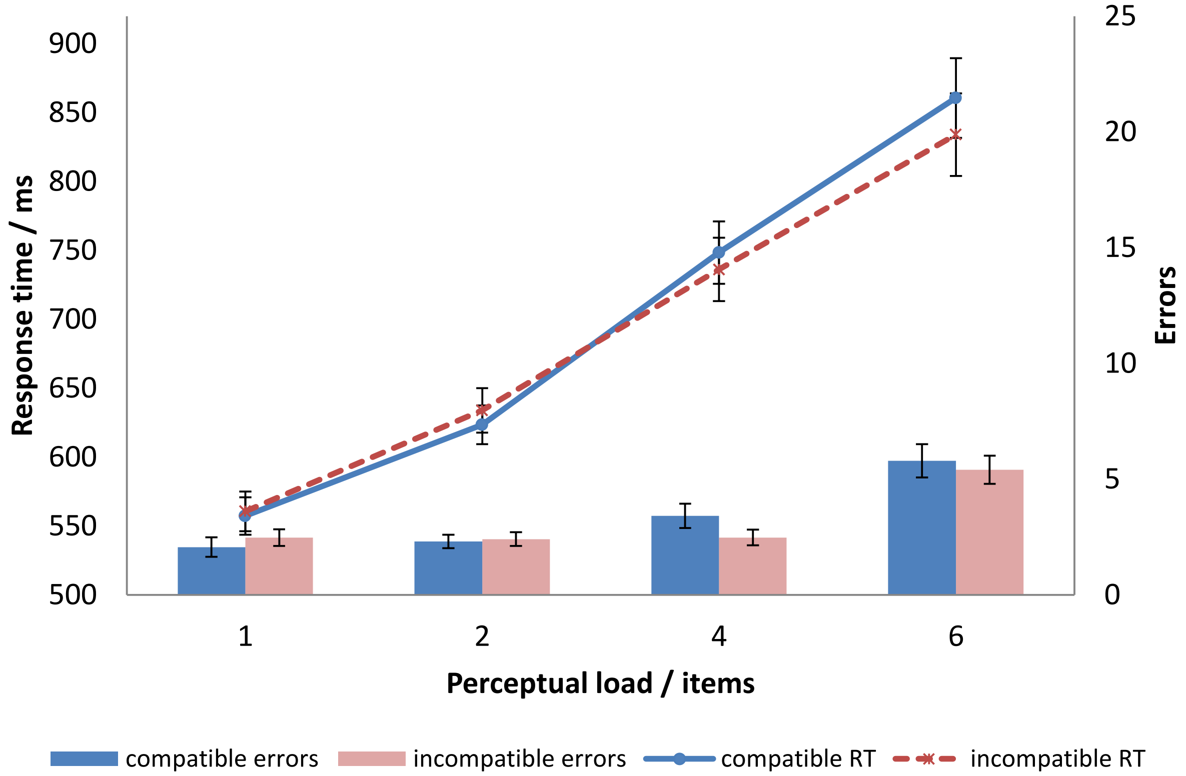

Figure 4. Response time and errors in Experiment 3 for compatible and incompatible distractor finger identity at each level of perceptual load. Error bars indicate standard error of the mean.

Figure 5

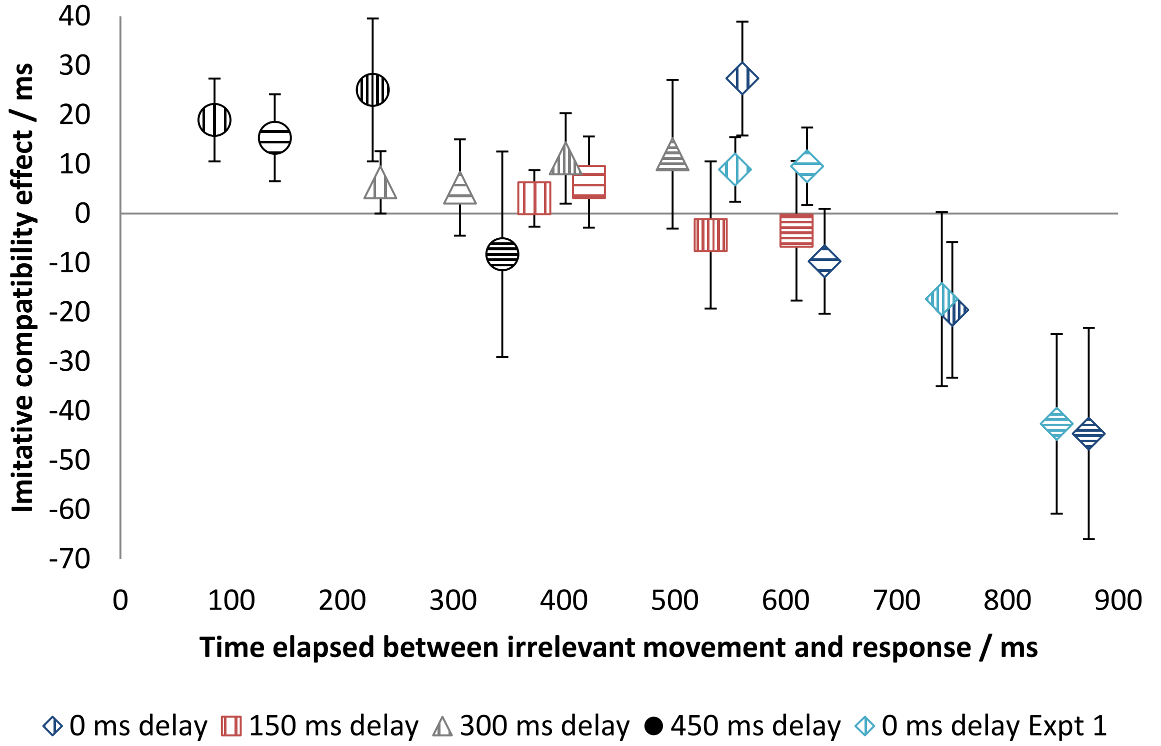

Figure 5. Imitative compatibility effect (response time on imitatively incompatible – compatible trials) at each level of perceptual load, plotted as a function of the elapsed time between the onset of the irrelevant finger movement and the response in Experiment 4. Data from Experiment 1 are included for comparison purposes. Error bars indicate standard error of the mean. For each level of delay, the perceptual load condition is indicated as follows: load 1: wide spaced vertical bars; load 2: wide spaced horizontal bars; load 3: narrow spaced vertical bars; load 4: narrow spaced horizontal bars.